xFitter (former HERAFitter) Project
Open Source QCD Fit framework

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SMU

on behalf of the xFitter team

Introduction

Precise knowledge of the PDFs are essential for predictions at hadron colliders

QCD factorisation:

$$\sigma \approx \hat{\sigma} \otimes PDF$$

Experimental Data:

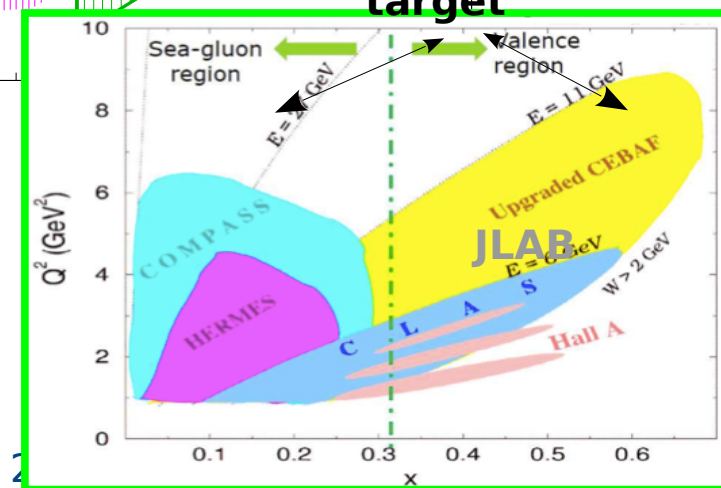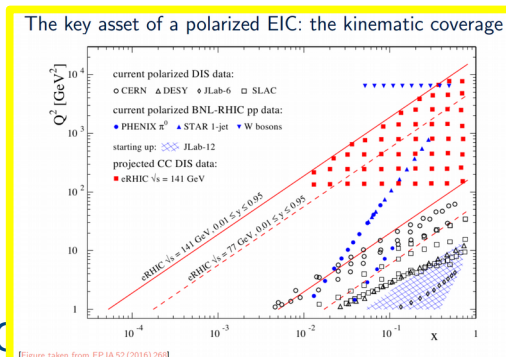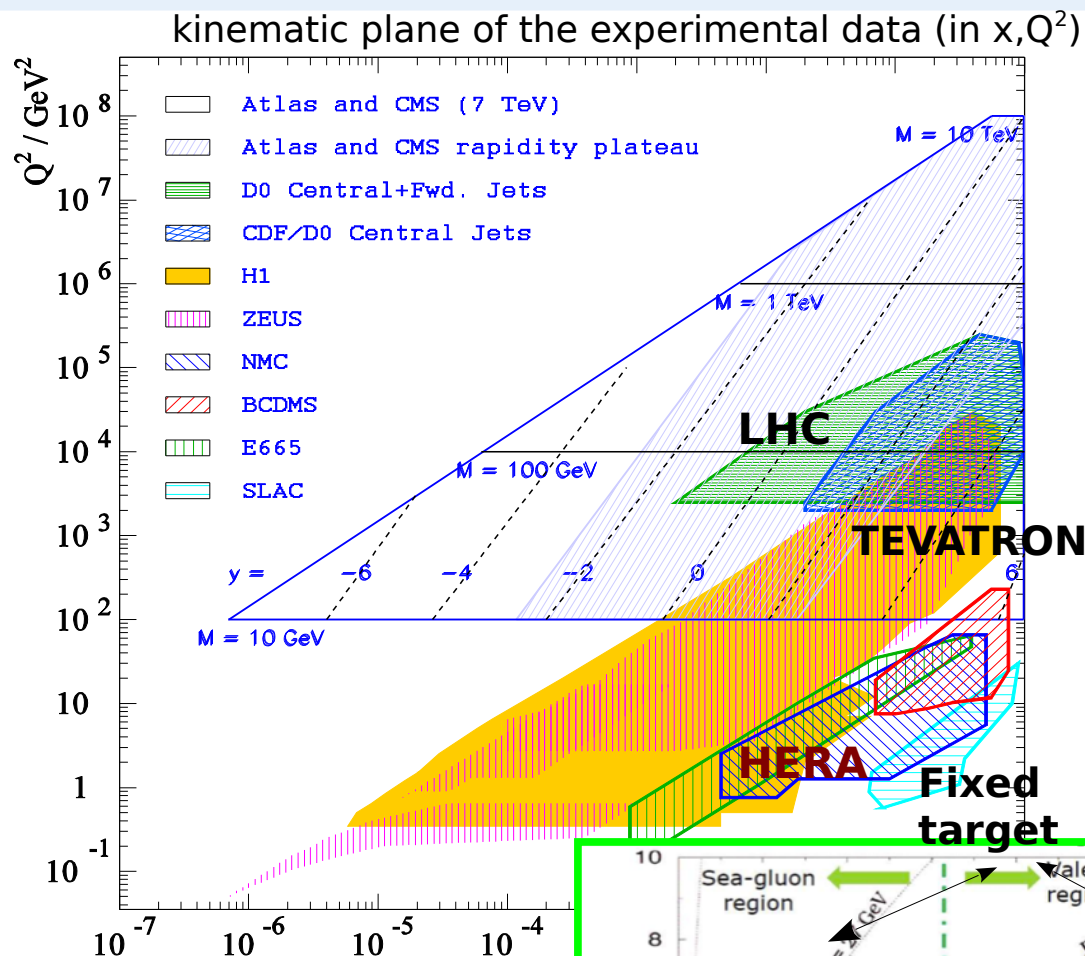→ a large variety of data from fixed-target and collider experiments

Theory:

→ intense theoretical developments

QCD Analysis:

→ available PDFs: CT/CJ, MMHT, NNPDF, ABM, HERAPDF, JR

… and **Tools**

kinematic plane of the experimental data (in x,Q²)

The key asset of a polarized EIC: the kinematic coverage

Tools for PDF determination

Available (open-source) tools for the PDF determination:

xFitter (former HERAFitter): an open-source package that provides a framework for the determination of the PDFs of the proton and for many different kinds of analyses in QCD

EPJC (2015), 75: 304, xfitter.org

OPENQCDRAD (ABM collaboration: numerical computation of all hard scattering cross sections (DIS structure function calculation including heavy quark contributions, W and Z production)

PRD86 (2012) 054009, www-zeuthen.desy.de/~alekhin/OPENQCDRAD

APFEL (used by NNPDF): a PDF evolution library, is a computer library specialized in the solution of DGLAP evolution equations up to NNLO in QCD and to LO in QED

arXiv.1310.1394, apfel.hepforge.org

QCDNUM: Fast QCD Evolution and Convolution (numerically solves the evolution equations for parton densities and fragmentation functions in pQCD)

Comp.Phys.Com.182:490,2011

ALPOS: an object-oriented data to theory comparison and fitting tool (profit from and exchange with xFitter experience)

http://desy.de/~britzger/alpos/

 → access from a public svn repository (via request)

xFitter Project

2011 Open Source Revolution:

first open source QCD Fit Platform which started the wave of sharing QCD fit codes

EPJC (2015), 75: 304

- A team of ~30 developers:
  - LHC/HERA/theory/independent
  - several releases since 2011
  - 33 publications that have used the framework [in total]

synergy between experiment and theory groups

provides a unique QCD framework to address theoretical differences:
→ benchmark exercises/collaborative efforts/topical studies
provides means to the experimentalists to optimise the measurements:
→ assess impact/consistency of new data

Dedicated studies [xFitter developers]

method in preserving correlation between PDFs extracted at different orders in pQCD
address consistency of Tevatron measurement and evaluate their collective impact on valence
determination of the running mass in $\overline{\text{MS}}$ scheme

xFitter Project

→ open access, no registration required

Welcome to xFitter (former HERAFitter)

Proton parton distribution functions (PDFs) are essential for precision physics at the LHC and other hadron colliders. The determination of the PDFs is a complex endeavor involving several physics process. The main process is the lepton proton deep-inelastic scattering (DIS), with data collected by the HERA ep collider covering a large kinematic phase space needed to extract PDFs. Further processes (fixed target DIS, ppbar collisions etc.) provide additional constraining powers for flavour separation. In particular, the precise measurements obtained or to come from LHC will continue to improve the knowledge of the PDF.

The xFitter project is an open source QCD fit framework ready to extract PDFs and assess the impact of new data. The framework includes modules allowing for a various theoretical and methodological options, capable to fit a large number of relevant data sets from HERA, Tevatron and LHC. This framework is already used in many analyses at the LHC.

Downloads of xFitter software package

💡 xFitter-1.2.2 release is publicly available.
All the xFitter releases can be accessed HERE.
All the former (HERAFitter) releases can be accessed 🌐 HERE.
Description: 🌐 http://arxiv.org/abs/1410.4412

xFitter Meetings

- User's Meetings: meetings to enhance communication between users and developers (open access)
- Developer's Meeting: technical weekly meetings to ensure communication among developers (restricted access)
- Steering Group's Meeting (restricted access)

Dubna Workshop: 18 – 20 February 2016

Schematic View of the xFitter Program

Main steps in QCD analysis:

Parametrise PDFs at the starting scale

→ multiple options for functional forms
    → Standard Polynomial, Chebyshev, etc

Evolve to the scale corresponding to data point

→ QCD(DGLAP) evolution codes [QCDNUM, APFEL]
→ kt ordered evolution, dipole models, QCD(DGLAP)+QED
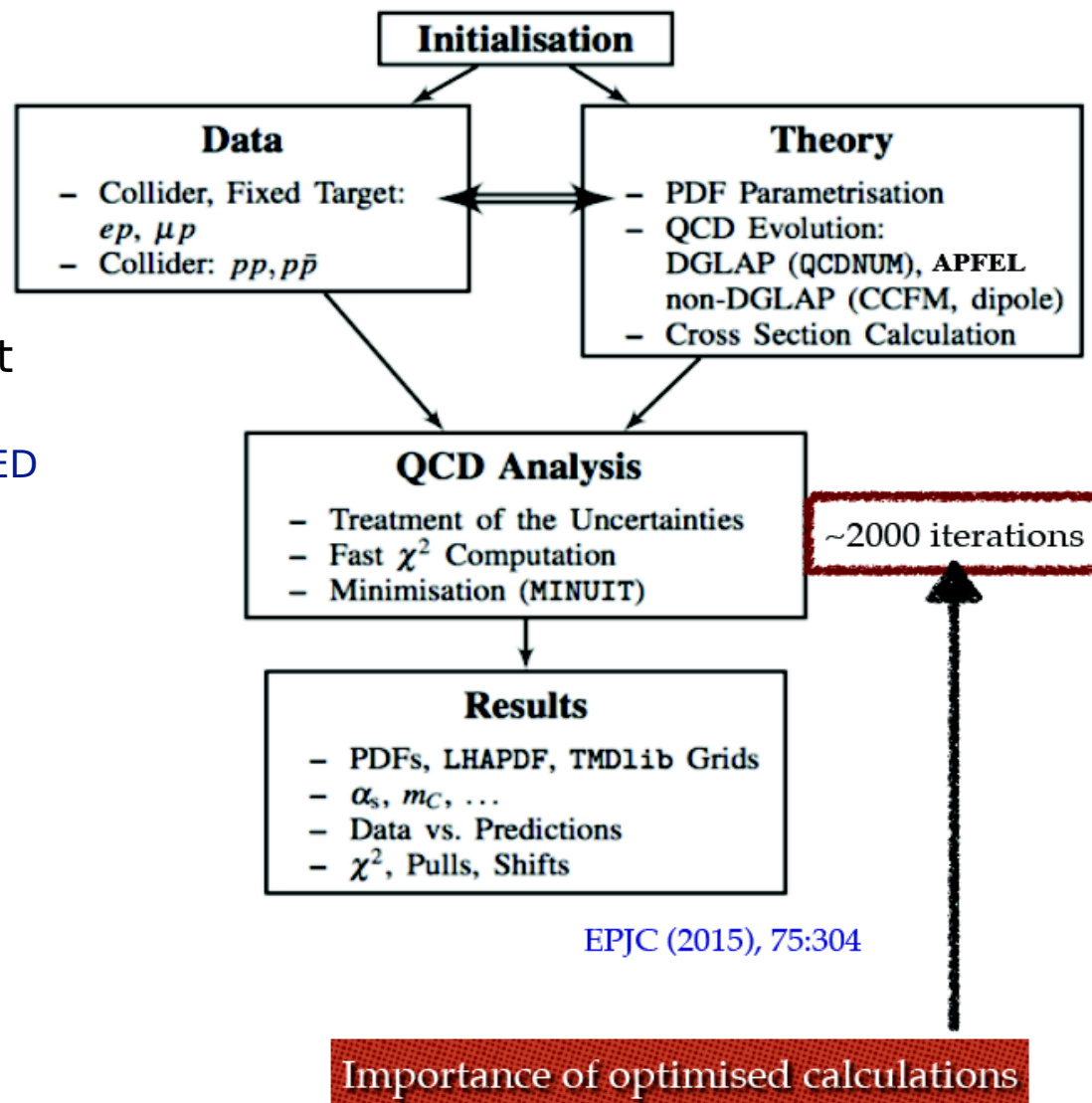
Calculate the cross section

→ various heavy flavour schemes:
    → RT, ACOT, FONLL, FFNS(ABM)
→ fast grid techniques interfaced to DY:
    → APPLGRID, FASTNLO

Compare with data via χ^2:

→ multiple forms to account for correlations

Minimize χ^2 with respect to PDF parameters

→ profiling, reweighting
→ fit: MINUIT, data driven regularisation

Initialisation

Data
- Collider, Fixed Target: ep, μp
- Collider: $pp, p\bar{p}$

Theory
- PDF Parametrisation
- QCD Evolution: DGLAP (QCDNUM), APFEL non-DGLAP (CCFM, dipole)
- Cross Section Calculation

QCD Analysis
- Treatment of the Uncertainties
- Fast χ^2 Computation
- Minimisation (MINUIT)

~2000 iterations

Results
- PDFs, LHAPDF, TMDlib Grids
- α_s, m_C, ...
- Data vs. Predictions
- χ^2, Pulls, Shifts

EPJC (2015), 75:304

Importance of optimised calculations

xFitter release xfitter-1.2.2

xFitter /
DownloadPage

www.xFitter.org

Releases of the xFitter QCD analysis package

- Versioning convention: **i.j.k** with
  - **i** - stable release
  - **j** - beta release
  - **k** - bug fixes.
- The release notes can be found in this attachment: xFitter_release_notes.pdf .
- Installation script for xFitter together with QCDNUM, APFEL, APPLGRID, LHAPDF Install-xfitter
- The script to download coupled data and theory files getter-xfitter.sh.

Date	Version	Files	Remarks
07/2016	**1.2.2**	xfitter-1.2.2.tgz	release with decoupled data and theory files
05/2016	**1.2.1**	xfitter-1.2.1.tgz	release with decoupled data and theory files
02/2016	**1.2.0**	xfitter-1.2.0.tgz	release with decoupled data and theory files

Documentation

- A list of datasets which can be downloaded with the help of getter script.
- Manual (under continuous improvement) can be accessed here.
- The **README** file (accessible via the package) gives an explanation for a quick start.
- The **INSTALLATION** file (accessible via the package) provides information for package installation and usage instructions.
- The package is licensed under GNU GPL, please see **LICENCE** for mode details (accessible via the package).

Sample data files:
LHC: ATLAS, CMS, LHCb
Tevatron: CDF, D0
HERA: H1, ZEUS, Combined
Fixed Target: …
User Supplied: …

By default only final combined HERA I+II data are distributed
→ getter-xfitter.sh script to download data with corresponding theory files
→ in directory 'datasets' located all available files

xFitter on GitLab

GitLab (CERN) is now the main repository of the project

→ open access to download for everyone (read only)

https://gitlab.cern.ch/fitters/xfitter

Commits from developers which have no CERN account handled via mirror-GIT public page

xfitter-1.2.2 vs xfitter-1.2.1

Several fixes were applied:

Release	Date	Description
xfitter-1.2.2	8.07.2016	• Fix in profiling due to multiple sign flips, affects also reweighting. • Fix in the output of PDFs, strange is symetrised to $(s + \bar{s})/2$. • Fix in calculation of theory error bands for parametrisation uncertainties for the `--therr` option. • Fix for `has_photon` LHAPDF variable and protection against LHAPDFQ0 with photon PDFs. • Fixes to dipole steering file in input steering file, updated now to current settings. • Added the H1 beauty data to the list of data files • Fix in the default theoretical parameters for HVQMNR to be used not in Fit mode. • Fix on warning message from Fastnlo. • Added examples in the example directory together with the tutorial slides from CTEQ 2016 school. • Fix in configuratuon for `--disable-root` option. • Fix in α_s interpolation and protection in overriding the output directories. • Fix in photon PDF sum rules.

CTEQ/MCnet School 2016
QCD and Electroweak Phenomenology
6-16 July 2016
DESY, Hamburg

http://qcd2016.desy.de

xfitter-1.2.2 examples (CTEQ school)

http://qcd2016.desy.de

Stefano Camarda
Ringailė Plačakytė

A list of educational examples are provided in the package - prepared for the CTEQ summer school 2016:

Exercise 1: PDF fit
→ learn the basic settings of a QCD analysis, based on HERA data only

Exercise 2: Simultaneous PDF fit and αs
→ learn the basic of an αs extraction using H1 jet data

Exercise 3: LHAPDF analysis
→ how to estimate impact of a new data without fitting:
→ profiling and reweighting techniques

Exercise 4: Plotting LHAPDF files
→ direct visualisation of PDFs from LHAPDF6 using simple python scripts

Exercise 5: Equivalence of χ^2 representations
→ understand different χ^2 representations
nuisance parameters and covariance matrix χ2 formulas

New Physics Cases in xFitter

QED PDFs up to NNLO QCD + LO QED in FFNS and VFNS are now available via evolutions in:

→ QCDNUM adjusted for DGLAP+QED [R. Sadykov]
  http://www.nikhef.nl/~h24/qcdnum

→ APFEL DGLAP+QED as used by NNPDF2.3 [V. Bertone et al]
  https://apfel.hepforge.org

→ plan to add NLO QED, interface APPLGRID to SANC
  https://apfel.hepforge.org/mela.html

Project SANC (former CalcPHEP): Support of Analytic and Numeric calculations for experiments at Colliders
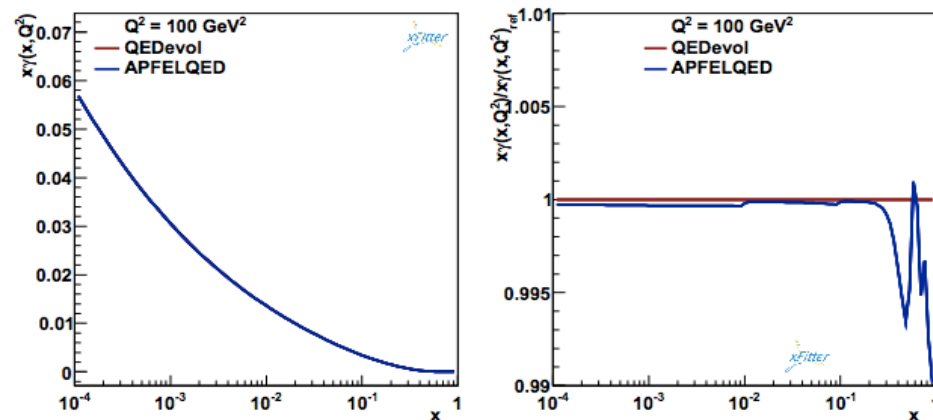
V. Bertone, R. Sadykov

New: NLO QCD + QED via APFEL in xFitter:

→ at LO QED, no corrections to the SFs are needed

→ at NLO QED, access to new diagrams: $\gamma^* \gamma \to qq$ and $\gamma^* q \to q\gamma$

→ implementing the $O(\alpha_s \alpha)$ and the $O(\alpha^2)$ corrections to the DGLAP splitting functions on top of the $O(\alpha)$ ones

→ implementing $O(\alpha_s^2 \alpha)$ and the $O(\alpha^2)$, $O(\alpha^2 \alpha_s)$ corrections to β functions

→ when including NLO QED corrections, not only the evolution is affected but also the DIS structure functions get corrected

ONLY ON GIT very new!

V. Bertone, APFEL
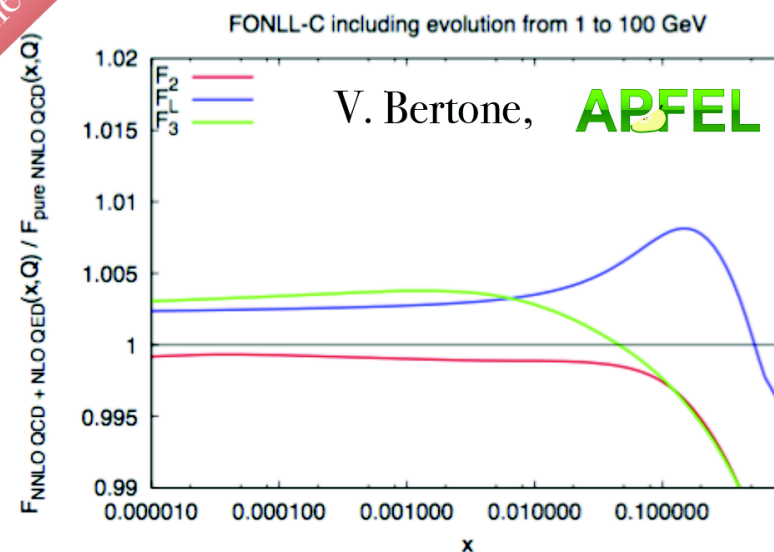
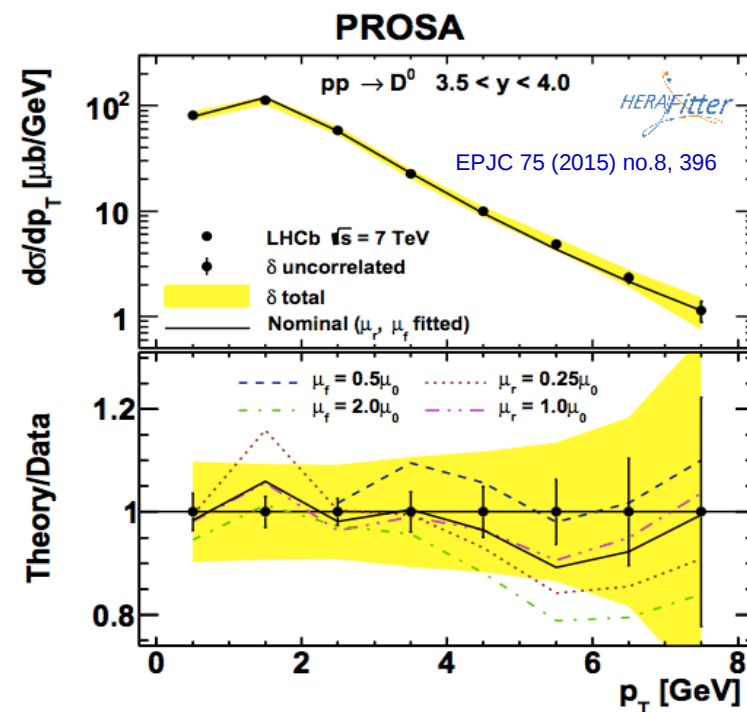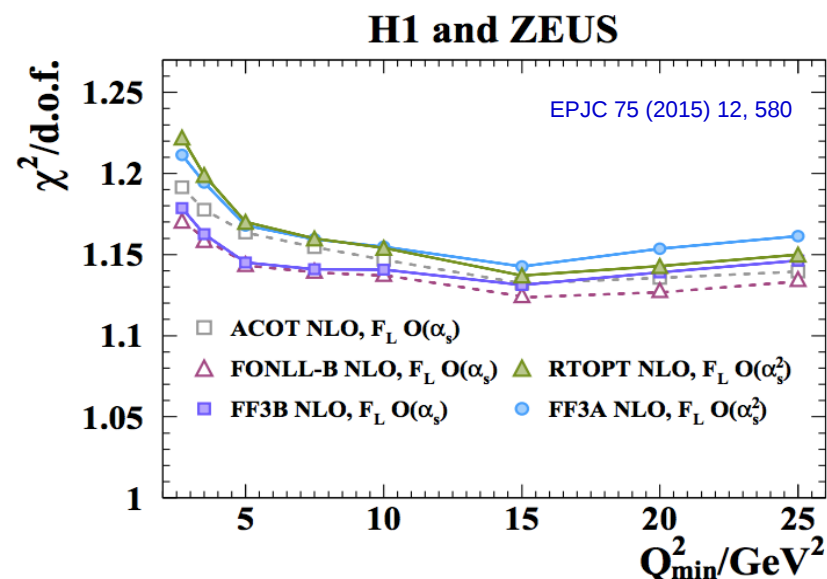# New Physics Cases in xFitter

Addition of new Heavy Flavour Scheme: **FONLL VFNS**

→ it is available thanks to collaboration with APFEL

→ various FONLL options available via interface to APFEL

  https://apfel.hepforge.org

→ ABM scheme was up-to-dated to OPENQCDRAD v 2.0b4

  http://www-zeuthen.desy.de/~alekhin/OPENQCDRAD

Interface to Mangano-Nason-Ridolfi (MNR, NPB 373 (1992) 295) theory code added in xFitter

→ was used for analysing the heavy-flavour production at LHCb and at HERA (via OPENQCDRAD)

  → use of FFNS for accounting of heavy quark masses at NLO

  → added corresponding LHCb data

Added extra reweighing option using Giele-Keller weights

H1 and ZEUS

EPJC 75 (2015) 12, 580

ACOT NLO, F_L O(α_s)
FONLL-B NLO, F_L O(α_s)   RTOPT NLO, F_L O(α_s^2)
FF3B NLO, F_L O(α_s)   FF3A NLO, F_L O(α_s^2)

PROSA

$pp \rightarrow D^0$ $3.5 < y < 4.0$

EPJC 75 (2015) no.8, 396

LHCb $\sqrt{s} = 7$ TeV
δ uncorrelated
δ total
Nominal (μ_r, μ_f fitted)

$\mu_r = 0.5\mu_0$ $\mu_r = 0.25\mu_0$
$\mu_f = 2.0\mu_0$ $\mu_r = 1.0\mu_0$

Results Obtained with xFitter

More than **30 public results** obtained using xFitter from the beginning of the project

https://www.xfitter.org/xFitter/xFitter/results

- LHC
- HERA
- Pheno
- Other
- xFitter

26 %

6 %

16 %

10 %

42 %
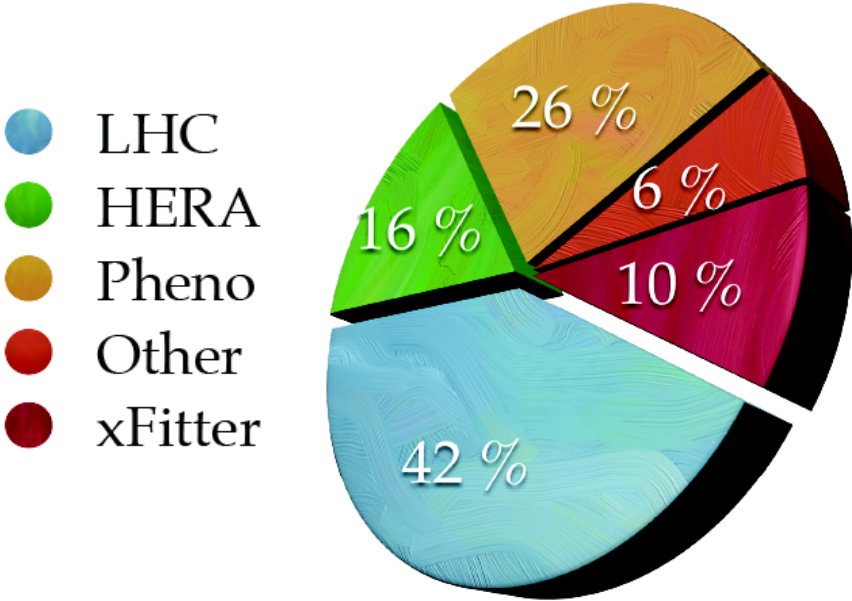
LHC experiments provide the main developments and usage of the xFitter platform

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xFitter publications:

	List of analyses using HERAFitter			
03.2016	xFitter and APFEL teams and A. Geiser	JHEP 1608 (2016) 050, arXiv:1605.01946	A determination of mc(mc) from HERA data using a matched heavy flavor scheme
03.2015	**HERAFitter** team	EPJC 75 (2015) 9, 458, arXiv:1503.05221	QCD analysis of W- and Z-boson production at Tevatron
10.2014	**HERAFitter** team	EPJC (2015), 75: 304, arXiv:1410.4412	HERAFitter Open Source QCD Fit Project
04.2014	**HERAFitter** team	EPJC (2014) 74: 3039, arXiv:1404.4234	Parton distribution functions at LO, NLO and NNLO with correlated uncertainties between orders

Results Obtained with xFitter: Examples
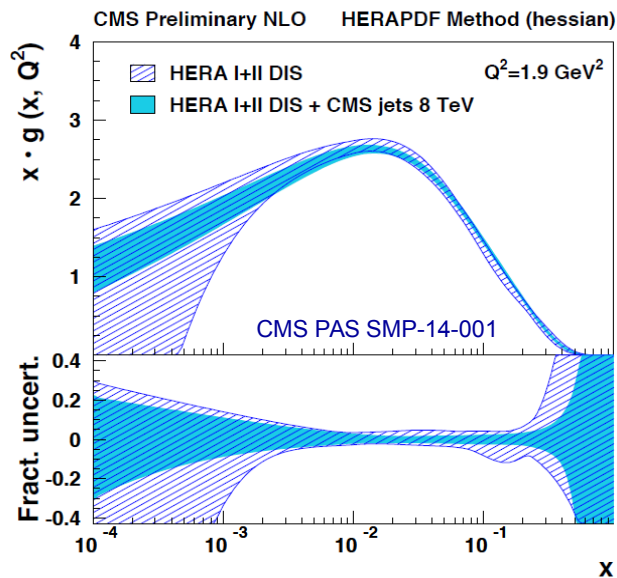
DIS inclusive processes in *ep*
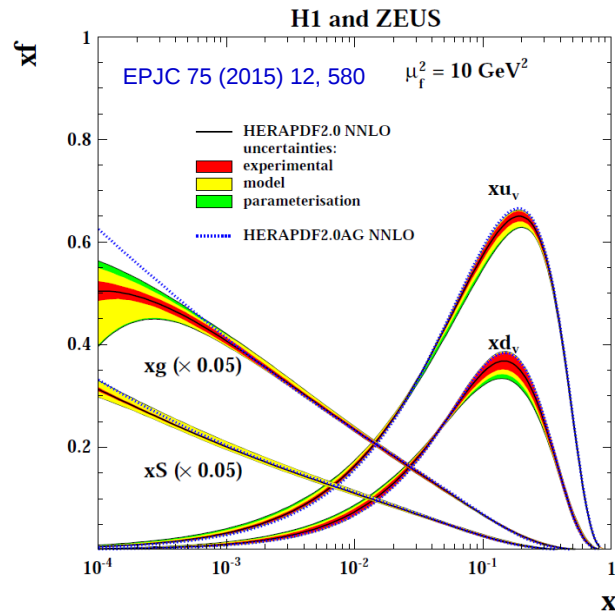
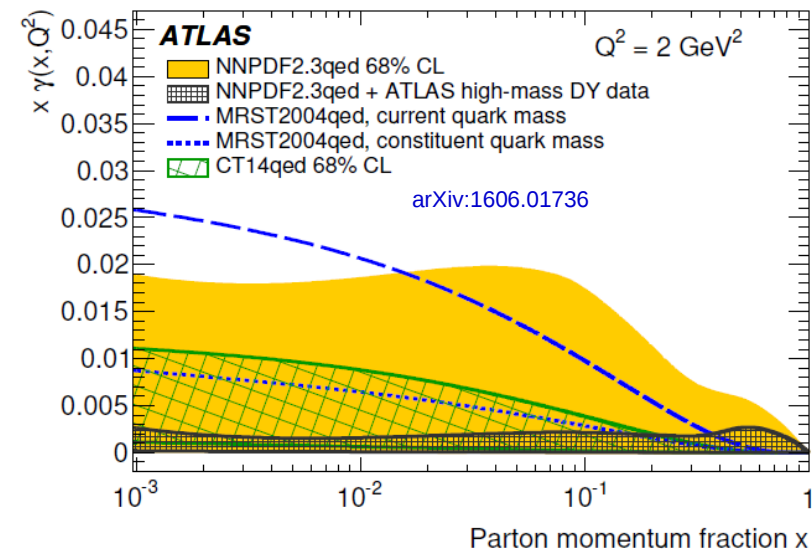**Drell-Yan processes** (*pp, ppbar*)

→ strange quark density determination
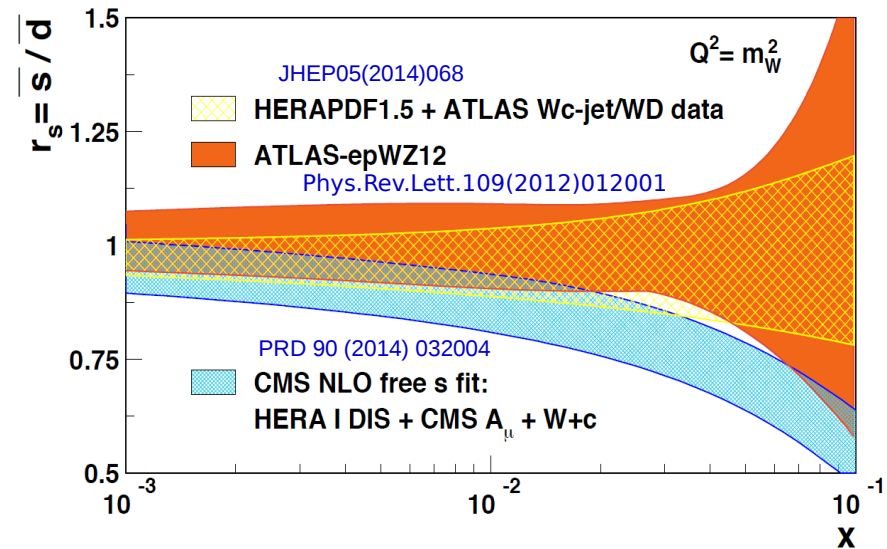
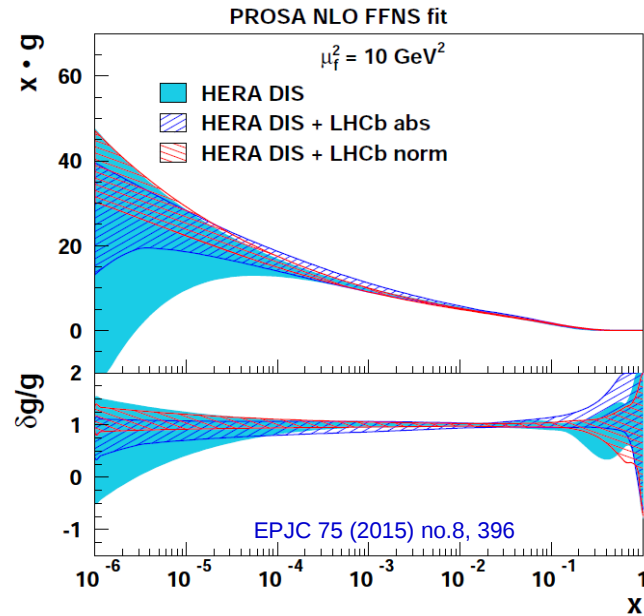**Jet production** (*ep, pp, ppbar*)

DY data sensitivity to photon PDF
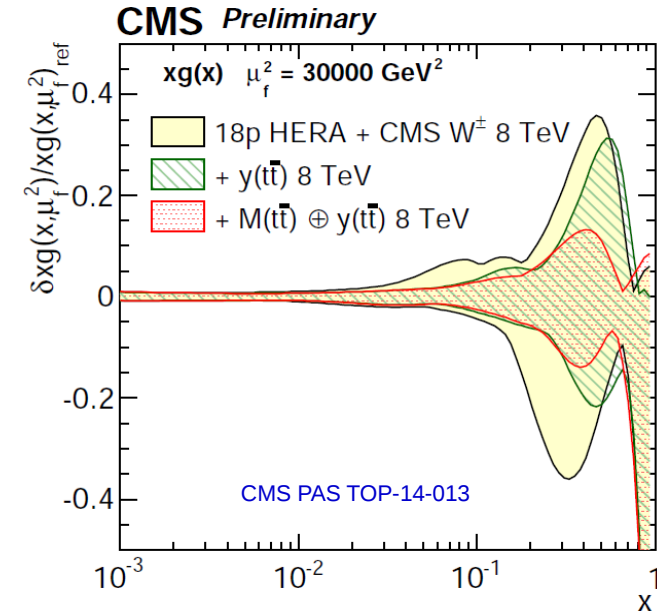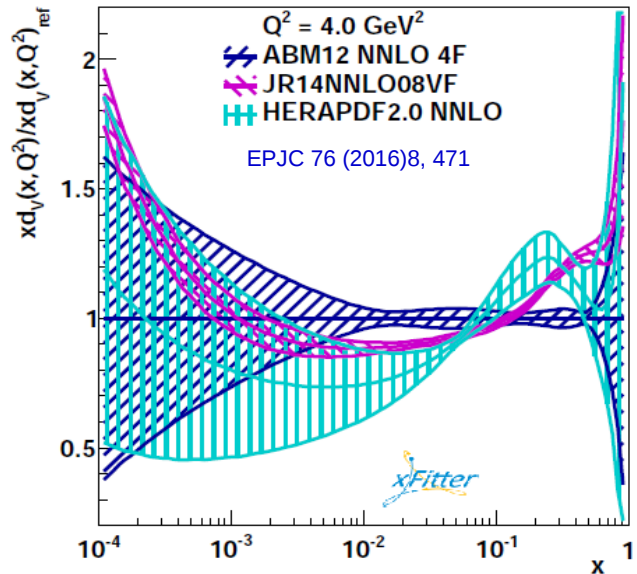
Results Obtained with xFitter: Examples

Heavy Quark production (*ep, pp, ppbar*)

PROSA NLO FFNS fit

$\mu_f^2 = 10\ \text{GeV}^2$

HERA DIS
HERA DIS + LHCb abs
HERA DIS + LHCb norm

EPJC 75 (2015) no.8, 396

Top-quark production (*pp, ppbar*)

CMS *Preliminary*

$xg(x)$ $\mu_f^2 = 30000\ \text{GeV}^2$

18p HERA + CMS $W^\pm$ 8 TeV
+ $y(t\bar{t})$ 8 TeV
+ $M(t\bar{t}) \oplus y(t\bar{t})$ 8 TeV

CMS PAS TOP-14-013

Evaluation of modern PDFs (benchmarking)

$Q^2 = 4.0\ \text{GeV}^2$
ABM12 NNLO 4F
JR14NNLO08VF
HERAPDF2.0 NNLO

EPJC 76 (2016)8, 471

PDF4LHC report (benchmarking)
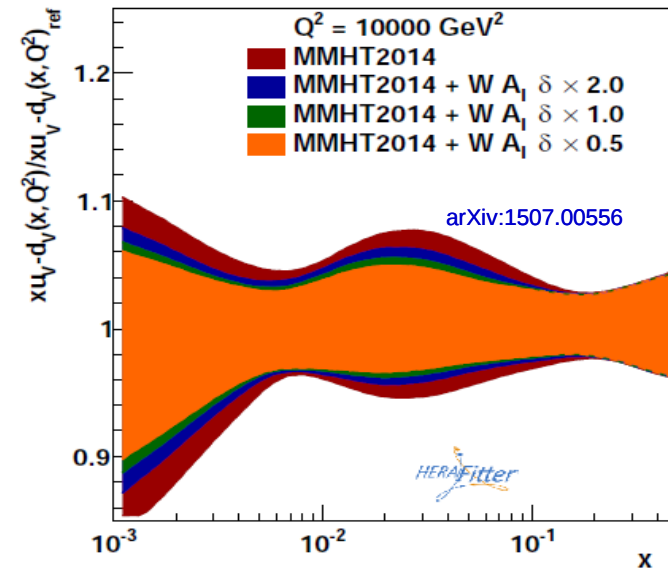
$Q^2 = 10000\ \text{GeV}^2$
MMHT2014
MMHT2014 + W A_l $\delta \times 2.0$
MMHT2014 + W A_l $\delta \times 1.0$
MMHT2014 + W A_l $\delta \times 0.5$

arXiv:1507.00556

Latest xFitter Developers Team Publication

A determination of mc(mc) from HERA data using a matched heavy-flavor scheme

xFitter Developers' team: Valerio Bertone, Stefano Camarda, Amanda Cooper-Sarkar, Alexandre Glazov, Agnieszka Luszczak, Hayk Pirumov, Ringaile Placakyte, Klaus Rabbertz, Voica Radescu, Juan Rojo, Andrey Sapranov, Oleksandr Zenaiev, Achim Geiser

(Submitted on 6 May 2016)

The charm quark mass is one of the fundamental parameters of the Standard Model Lagrangian. In this work we present a determination of the MSbar charm mass from a fit to the inclusive and charm HERA deep-inelastic structure function data. The analysis is performed within the xFitter framework, with structure functions computed in the FONLL general-mass scheme as implemented in APFEL. In the case of the FONLL-C scheme, we obtain mc(mc) = 1.335 +- 0.043(exp) +0.019 −0.000(param) +0.011 −0.008(mod) +0.033 −0.008(th) GeV. We also perform an analogous determination in the fixed-flavor-number scheme at next-to-leading order, finding mc(mc) = 1.318 +- 0.054(exp) +0.011 −0.010(param) +0.015 −0.019(mod) +0.045 −0.004(th) GeV, compatible with the FONLL-C value. Our results are consistent with previous determinations from DIS data as well as with the PDG world average.

The extraction of $m_c(m_c)$ was performed using FONLL scheme in terms of the $\overline{MS}$ masses → improves perturbative convergence

→ combined HERA I + II charm production and DIS cross sections

→ FONLL-C scheme used – NLO accuracy in the massive sector

→ also tested in FFNS (fixed flavour number scheme) at NLO

*pole mass definition suffers from non-perturbative effects which result in an intrinsic uncertainty of order Λ_{QCD}*

→ $m_c(m_c)$ value is determined from a parabolic minimum of the global χ^2 scan vs $m_c(m_c)$ with 1σ uncertainty determined from $\Delta\chi^2$ variation

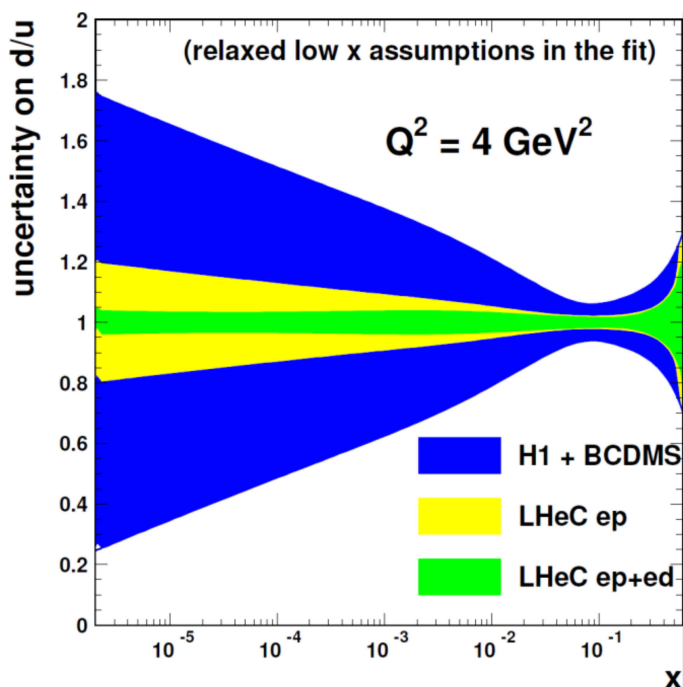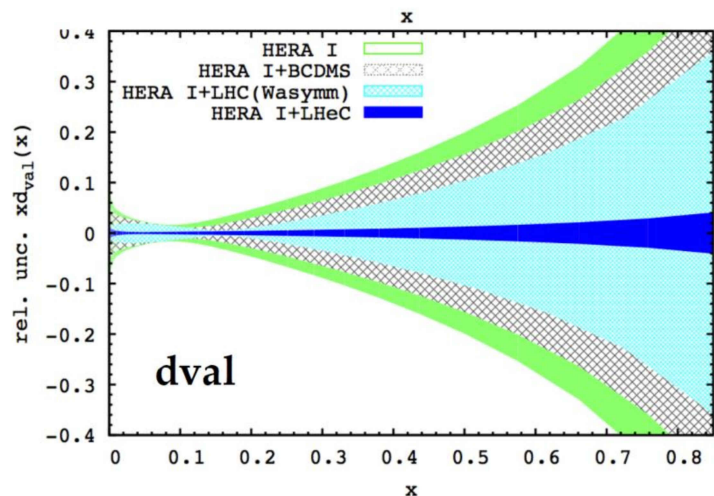→ $m_c(m_c)$ measurement is comparable to previous determinations from DIS as well as PDG world average:
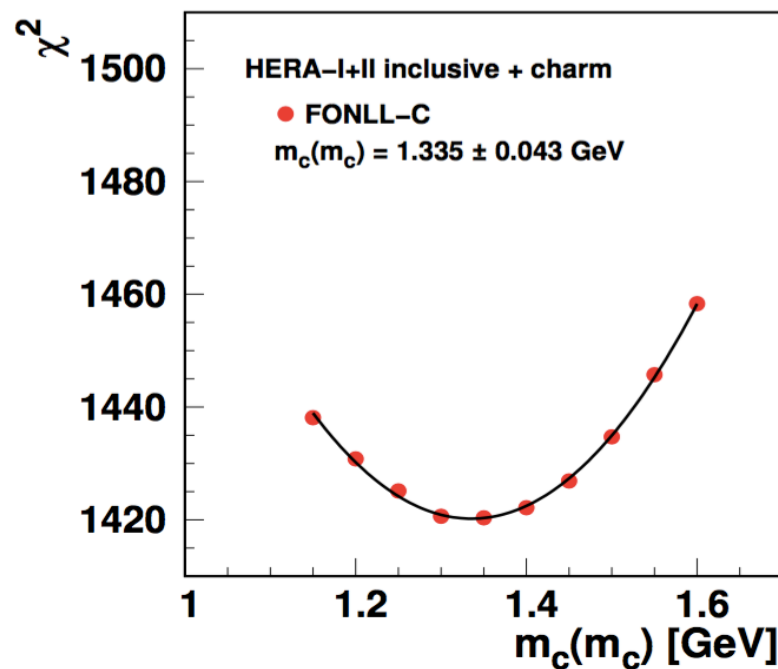
FONLL-C:

$$m_c(m_c) = 1.335 \pm 0.043(\text{exp})^{+0.019}_{-0.000}(\text{param})^{+0.011}_{-0.008}(\text{mod})^{+0.033}_{-0.008}(\text{th}) \text{ GeV}$$
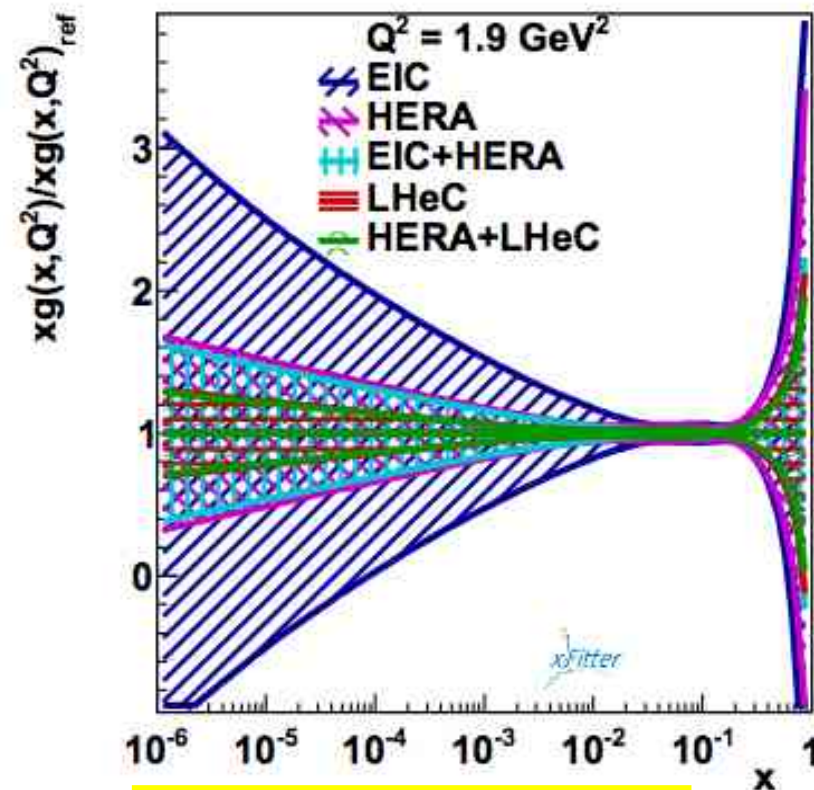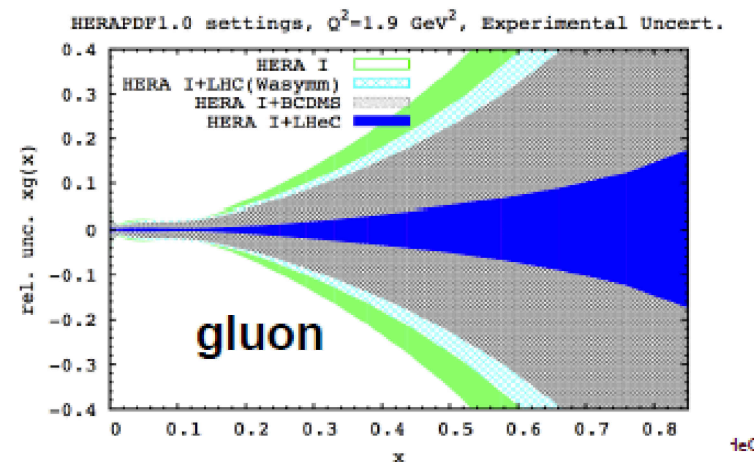
LHeC Studies

xFitter
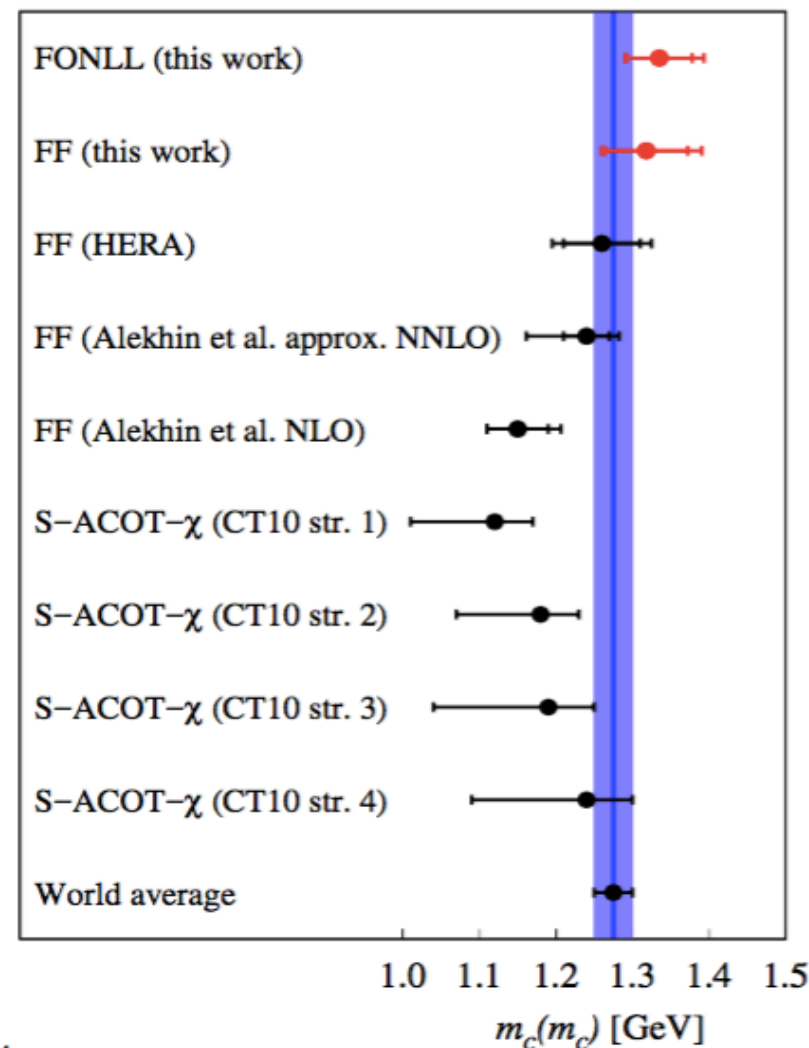
→ Compute PDFs for future facilities
→ Determine discovery reach



See Max Klein's talk Thursday

Profiling W$^{\pm}$ in Proton-Lead Collisions

→ Use nCTEQ15 LHAPDF grids
→ Use FEWZ for W cross section calculations
→ Input LHC pPb data
→ Use xFitter Profiling utilities

```
! This theory file a test file
! generated from cms_Wm_pPb/tab1_NLO_nCTEQ15/0-NLO.w.output_FEWZextractor.pi
!
&Data
    Name  = 'cms_wm_fig3b_rew_theory'
    NData = 10                          ! Number of data points
    NColumn = 35
    ColumnType = 2*'Bin','Theory',
    ColumnName = 'bin_min','bin_ma

    Percent = 35*false
&End
-3.210000   -2.210000    68.741530
-2.710000   -1.710000    73.166300
-2.210000   -1.210000    77.117926
-1.710000   -0.710000    76.802215
-1.210000   -0.210000    74.028980
-0.710000    0.290000    71.703561
-0.210000    0.790000    66.724986
 0.290000    1.290000    60.784235
 0.790000    1.790000    55.089179
 1.290000    2.290000    50.663899
```
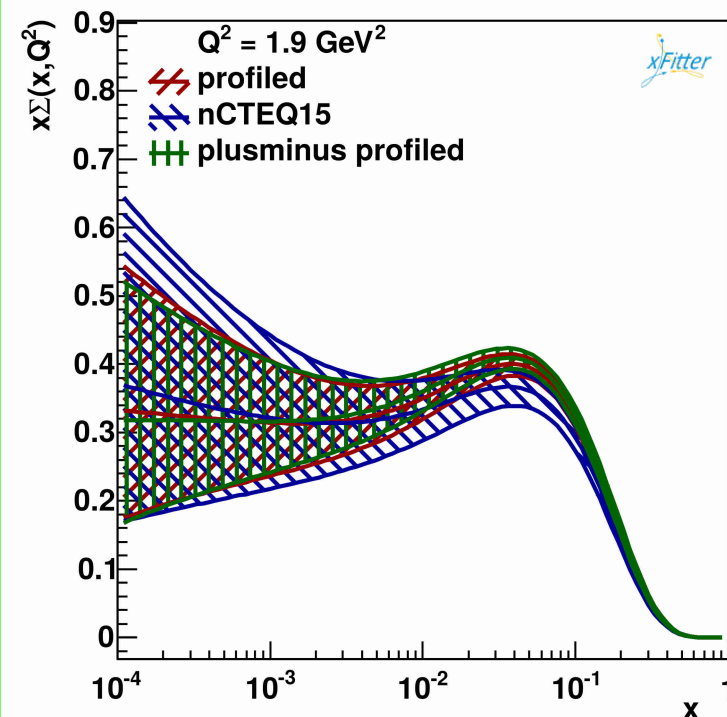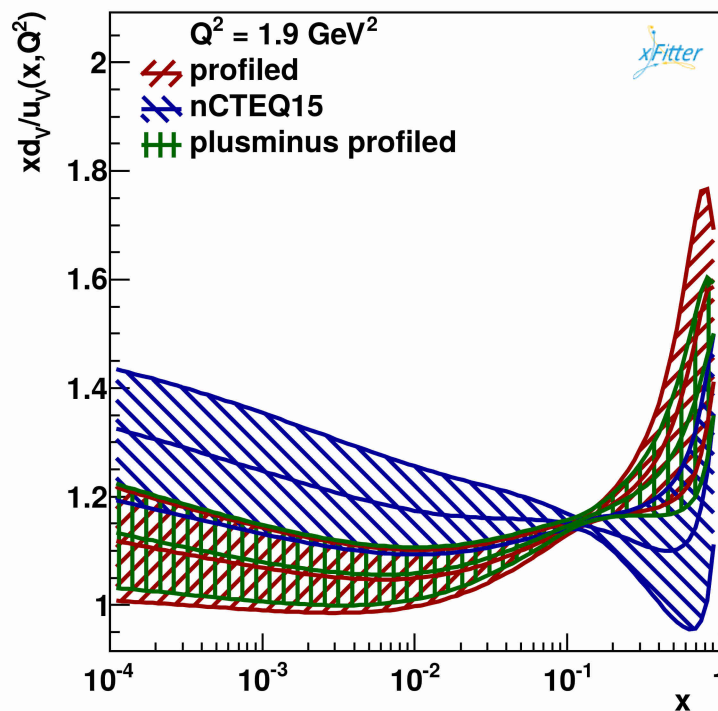
6.491652	76.373931	75.46185
4.670278	73.321801	72.60121
2.562872	70.763443	70.600849
7.724555	65.643148	66.244718
1.834261	74.572306	76.142279
0.149144	53.990219	55.656449
1.320199	39.691263	41.157364

Both profiling & reweighting available

Thanks to Eric Godat & Voica Radescu

TMD (uPDFs) in xFitter via CASCADE

→ work in progress
→ sample results shown
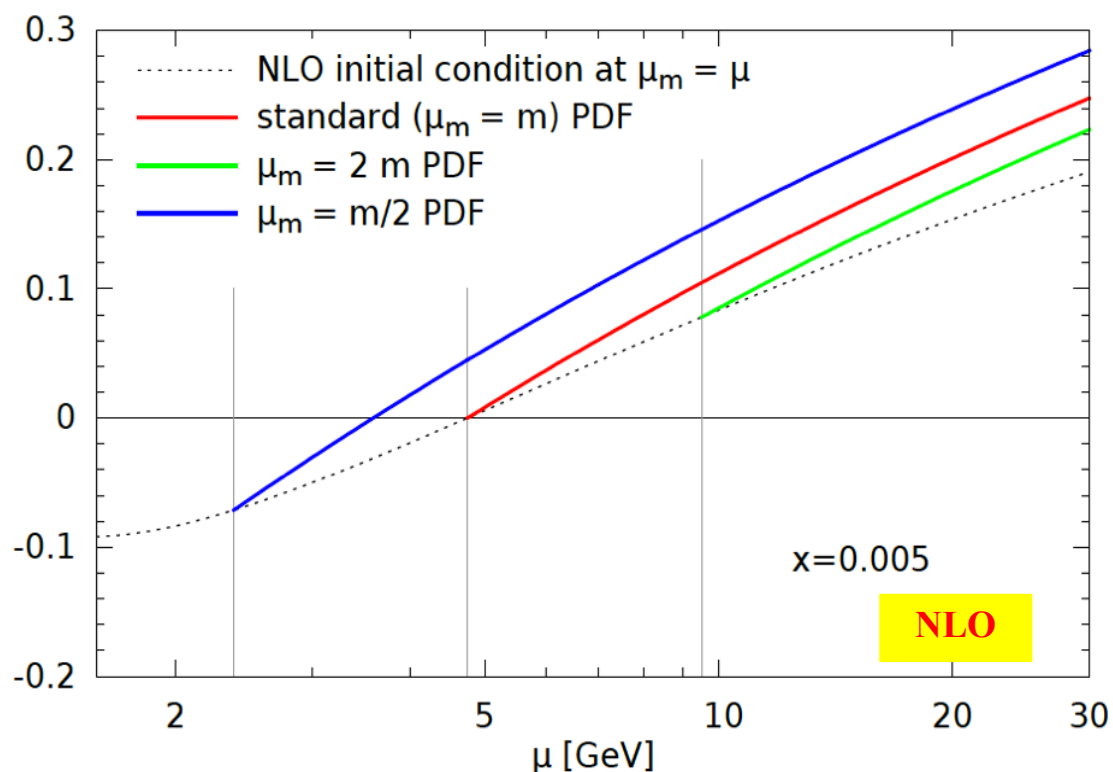→ evolve in Q with DGLAP, BFKL, or CCFM

x=10^{-1}

gluon

K$_T$ distribution

x=10^{-2}

x=10^{-3}
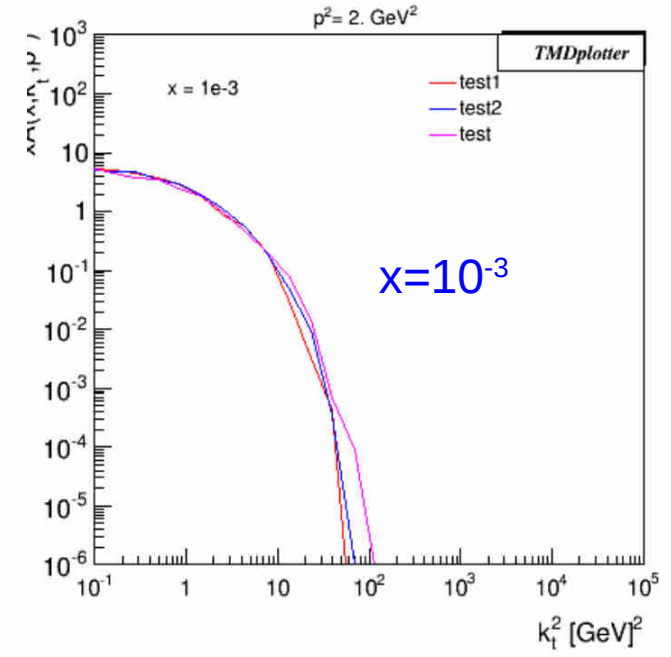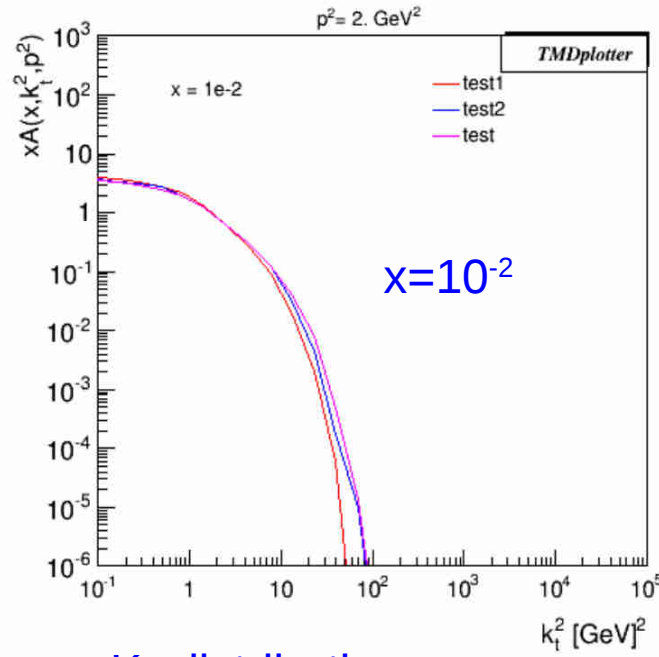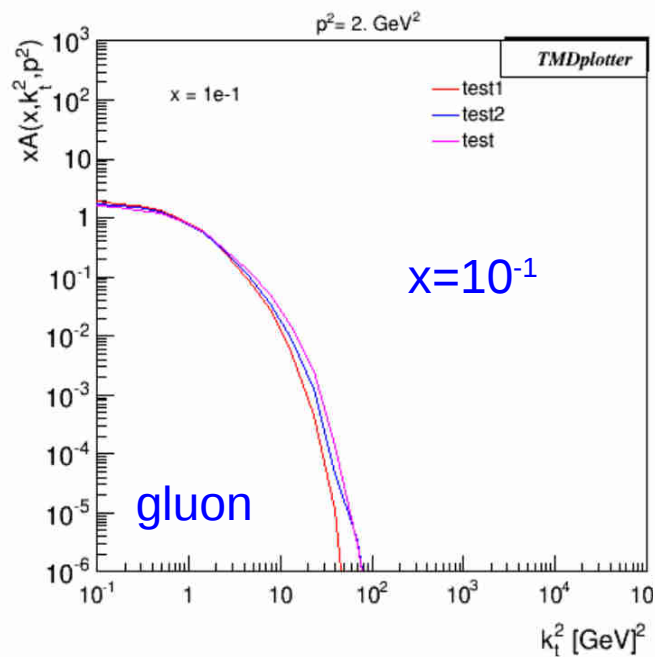
Ola Lelek, Francesco Hautmann, Hannes Jung
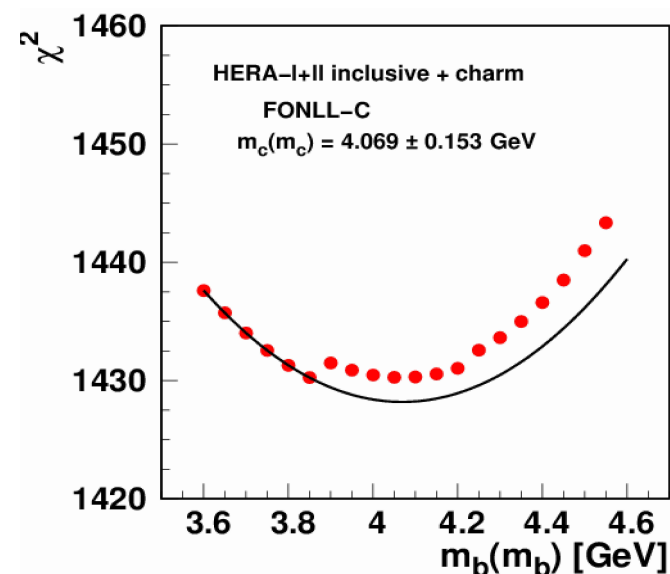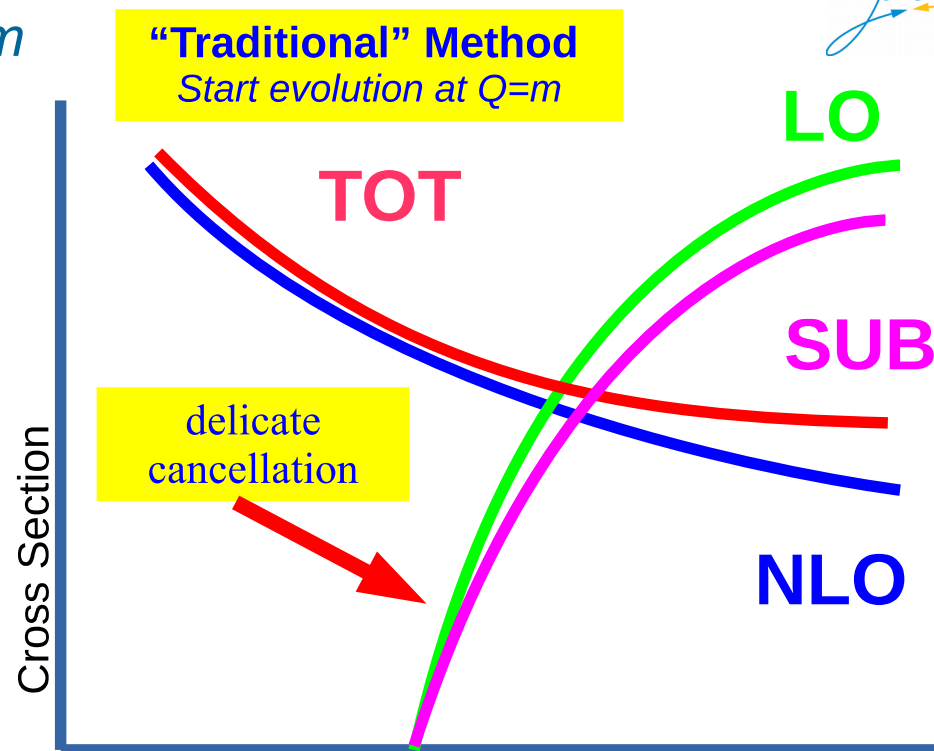*xFitter Workshop, Dubna February 2016*

Variable Matching Scale μ_m

→ Freedom to Choose Matching Scale μ_m
→ Avoid delicate cancellations
→ Select scale "away" from data

bottom PDF at NLO

- ⋯ NLO initial condition at $\mu_m = \mu$
- — standard ($\mu_m = m$) PDF
- — $\mu_m = 2\,m$ PDF
- — $\mu_m = m/2$ PDF

$x = 0.005$

NLO

Thanks to Valerio Bertone

"Traditional" Method
Start evolution at Q=m

LO

TOT

SUB

NLO

delicate cancellation

Cross Section

HERA–I+II inclusive + charm
FONLL–C
$m_c(m_c) = 4.069 \pm 0.153$ GeV

χ^2

$m_b(m_b)$ [GeV]

Tools for PDF Analysis

→ LHAPDF Standard
→ Interface to Python
→ ManeParse Mathematica Package

```
# loop over Q values
for iq,qq in enumerate(Qval):
    # divide it into two subplot vertically
    subplot2grid((1,2),(0,iq))
    semilogx(xvalues, fulllead_x_vals[qq], label='$xu(x)\ \
    semilogx(xvalues, fulliron_x_vals[qq], label='$xu(x)\ \
    legend(loc=3)
    text(2e-3,0.2, "$Q={}\ GeV$".format(qq))
    xlabel('$x$',fontsize=18)
    ylabel('$xf(x)$',fontsize=18)
```
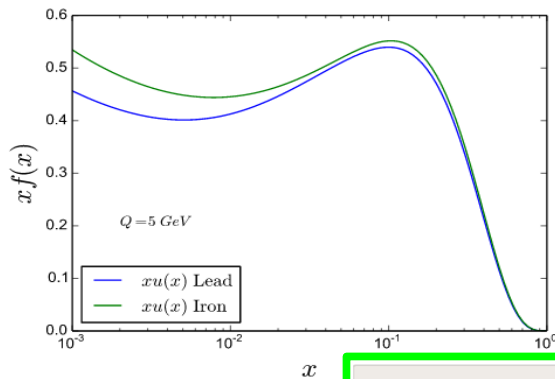

Thanks to Florian Lyonnet & Eric Godat
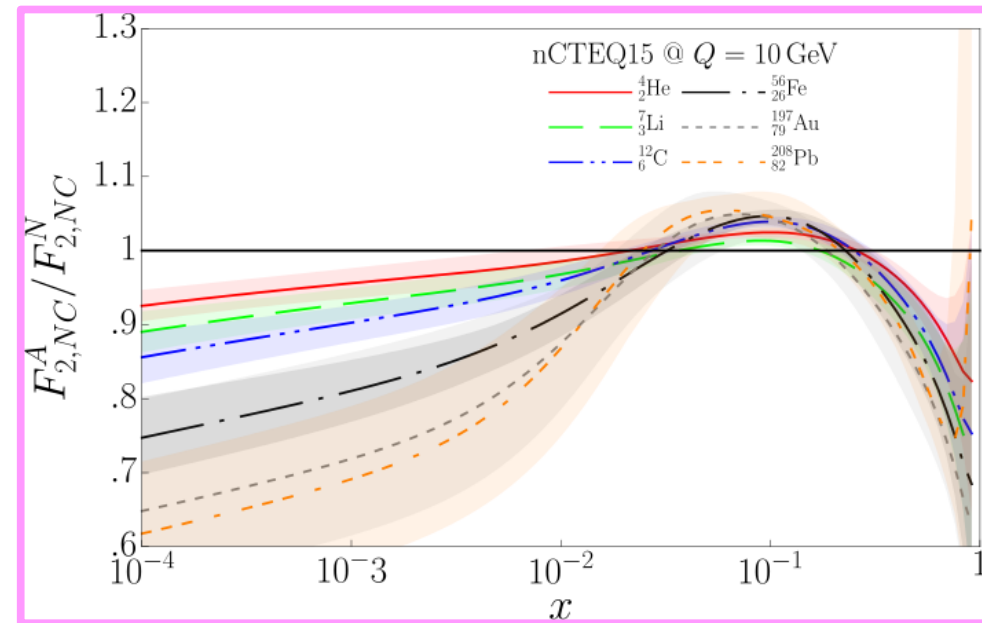
PDF Set
MSTW2008nnlo68cl [7]
CT14nnlo [8]
NNPDF30_nnlo_as_0118_nf_6 [9]
HERAPDF20_NLO_VAR [10]
abm12lhc_5_nnlo [11]
CJ15nlo [12]
nCTEQ15_1_1 [13]
nCTEQ15_208_82 [13]
ct10.pds [14]
ctq66m.pds [2]
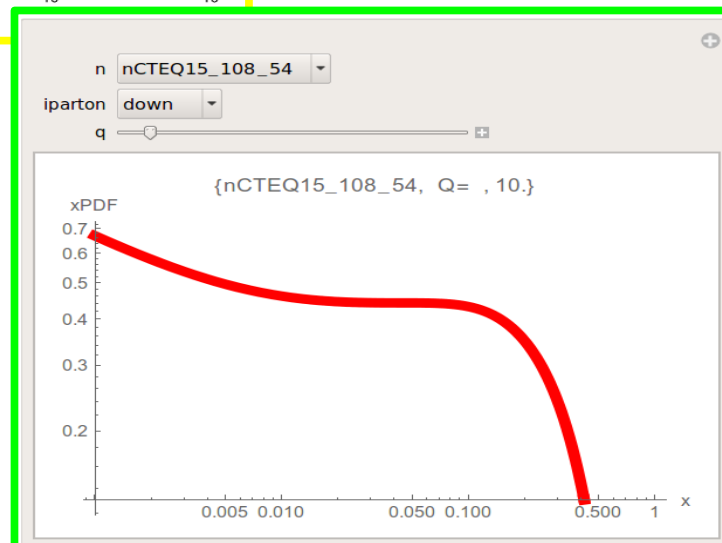
Welcome to **APFEL** online cluster!

Summary
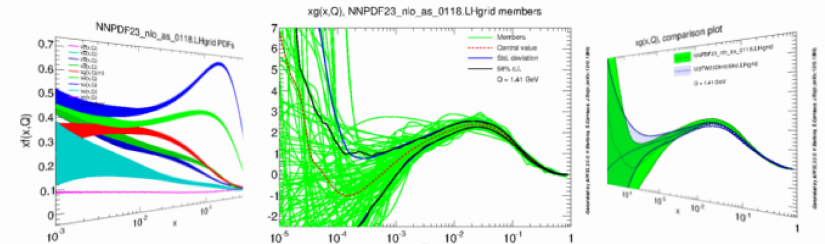
> **xFitter** project - a multi-functional QCD framework well integrated into the high energy community (both, experimental and theory) *EPJC (2015) 75: 304*

→ many active developments thanks to the close collaboration with experiments and theory groups

   → technical updates include usage of GitLab and HEPFORGE

→ **xfitter-1.2.2** is latest (recommended) release

→ over 30 public results obtained using xFitter (main applications are from LHC)

→ several published dedicated physics studies (developers team publications), more studies are ongoing

→ foreseen future physic (low-x phenomenology, nuclear PDF, etc...) and technical developments (improved user interface for PDF parametrisation form, data cards, python interface, etc...)

→ useful for EIC projects, and room for suggestions and contributions

we welcome new ideas and developers :)

www.xfitter.org

Back-up Slides

Technical Changes (since xfitter-1.2.0)

- **Change of name of executables:**
  - FitPDF   —> xfitter
  - DrawPdfs   —> xfitter-draw
  - DrawResults   —> xfitter-draw
  - Postproc   —> xfitter-process
- Note that in the previous releases there was a theoryfiles directory

  - —> now theoryfiles are stored with datafiles to be in sync

Installation:
  - xfitter-1.2.0 is compatible with new QCDNUM version > 17.01.10
    - QCDNUM is available now also with autotools installations
    - QCDNUM provides now access to more than standard 13 PDFs, e.g. photon PDF can be added
  - Installation of the xfitter-1.2.0 can also be configured via prefix
  - Added the possibility to disable root

- Theory formats in xfitter (usage/parsing) have been unified between FASTNLO and APPLGRID
  - old format for FASTNLO is still operational

- Profiling and Reweighing codes now use same general infrastructure

- Possibility to access directly PDFs as stored in LHAPDF (surpassing QCDNUM)

  - LHAPDFNATIVE option added   16

xFitter on Hepforge: data access

http://xfitter.hepforge.org/

- Home
- Source Code
- List of Data Files
- xFitter Wiki
- xFitter Releases
- Contact

An Open Source QCD Fit Project

Welcome! This site is under development.
(use: xFITTER site .)

This page contains the list of publicly available experimental data sets (with corresponding theory grids if available) in the xFitter package.
To download data set please click on the arXiv link (and open/save tar.gz file).

No	Collider	Experiment	Reaction	arXiv	Readme
1	fixedTarget	bcdms	inclusiveDis	cern-ep-89-06	README
2	hera	h1	beautyProduction	0907.2643	
3	hera	h1	inclusiveDis	1012.4355	
4	hera	h1	jets	0706.3722	README
5	hera	h1	jets	0707.4057	README
6	hera	h1	jets	0904.3870	README
7	hera	h1	jets	0911.5678	README
8	hera	h1	jets	1406.4709	README
9	hera	h1zeusCombined	charmProduction	1211.1182	
10	hera	h1zeusCombined	inclusiveDis	0911.0884	
11	hera	h1zeusCombined	inclusiveDis	1506.06042	
12	hera	zeus	beautyProduction	1405.6915	
13	hera	zeus	diffractiveDis	0812.2003	
14	hera	zeus	jets	0208037	
15	hera	zeus	jets	0608048	
16	hera	zeus	jets	1010.6167	
17	lhc	atlas	drellYan	1305.4192	
18	lhc	atlas	drellYan	1404.1212	
19	lhc	atlas	jets	1112.6297	

Complementary information about the project (to xfitter.org)

→ possibility to download **data** files (including theory)

→ updated automatically with new data added to svn

will include script to download all data at once

Your feedback is welcome
(via email xfitter-help@desy.de)